ENGINEERING REPORT

FUEL CELL POWERED HIGHWAY ADVISORY RADIO

Prepared for:
State of New Jersey, Department of Transportation, Bureau of Transportation Technology

Prepared by:
H Power Corp. Advanced Engineering Development Dept.

ABSTRACT

From 1997 through 1999 H Power developed an ammonia-air fuel cell system for use as the primary power source for a highway advisory radio (HAR). This system, prior to being employed in an HAR, was bench tested and upgraded at H Power's facility. After being employed in the HAR (Figure 1) the system was tested outdoors at H Power then transported to a DOT site for field-testing. This system, powering an active HAR transmitter, was operated intermittently between 10/06/98 and 02/11/99 at DOT's Bedminster facility. Testing was suspended when system shutdowns were encountered due to freezing of water in system piping at very low ambient temperatures.

The H Power 30 watt system supplied under this program was probably the smallest, complete ammonia-air fuel cell system ever constructed and tested. Thermal losses at sub-freezing temperatures, exacerbated by the small size of the system, became the most critical factor affecting system operation.

BACKGROUND

Fuel cells produce electricity through the electrochemical combination of a fuel and oxygen. Although much effort has been performed to develop fuel cells using common fuels directly, most systems presently in use first convert the fuel to hydrogen in a fuel processor or run directly on stored hydrogen.

Ammonia is an ideal fuel for use in a practical fuel cell system. It is easily converted to a hydrogen-rich feed stock in a thermal dissociator, is readily available, low cost, and provides a higher energy storage density, including tankage, than other hydrogen sources.

Fuel cell systems utilizing dissociated ammonia as a fuel have been constructed and reported in the literature in the past. Engelhard Industries constructed a 100-watt and four 300-watt systems. Three of the 300-watt systems were constructed for the U.S. Air Force. The fourth was constructed for a major communications utility and was operated, out-of-doors, for in excess of 18 months.

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DESCRIPTION OF SYSTEM

The HAR with the ammonia fuel system installed is shown in Figure 1 below. Major components are identified.

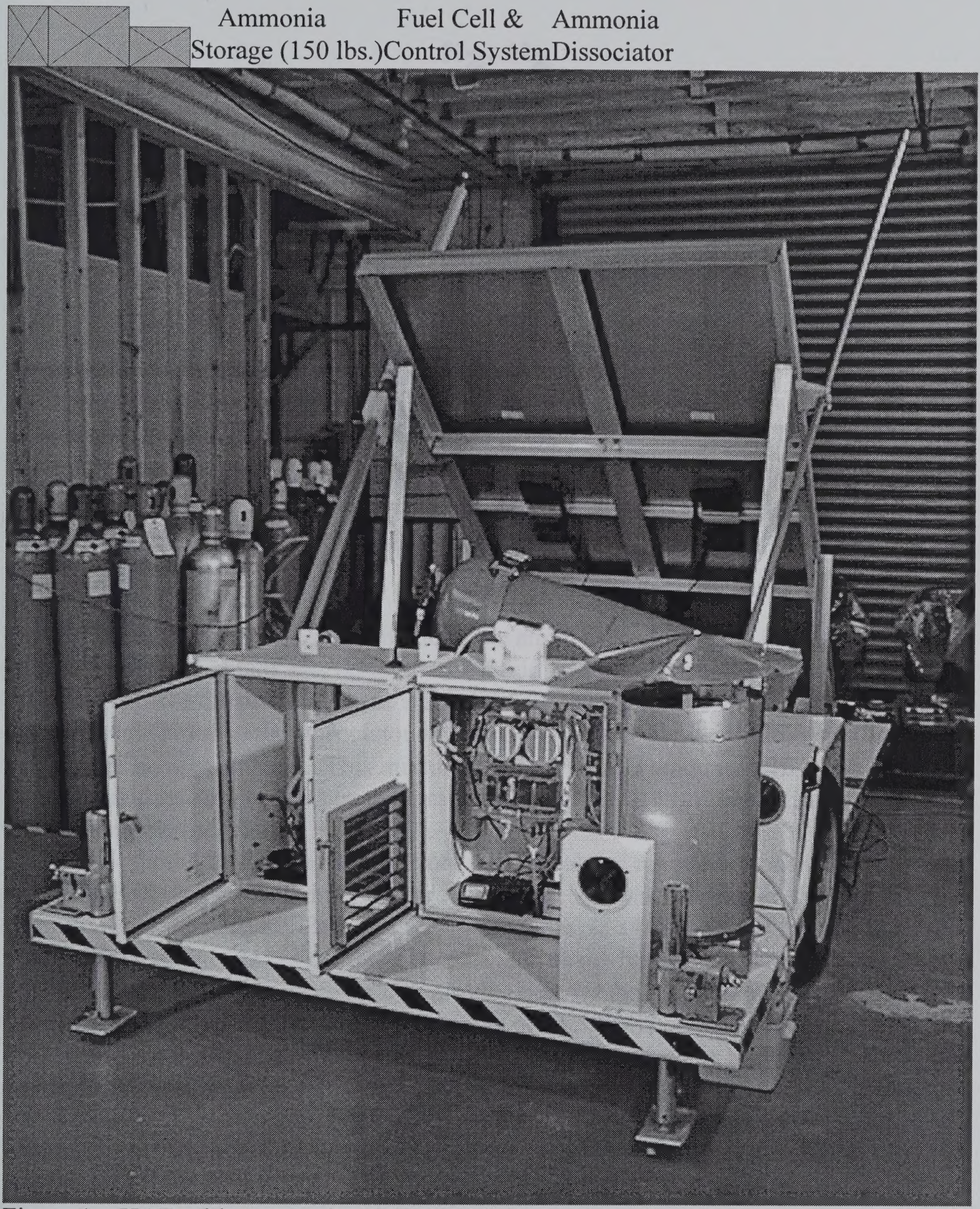

Figure 1 – HAR with Ammonia-Air Fuel Cell System Installed

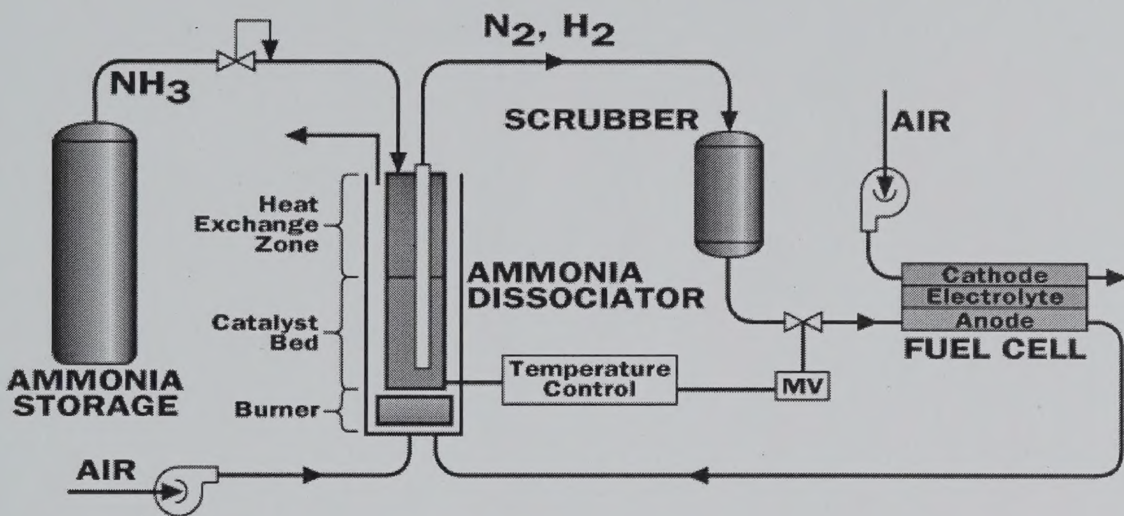

Figure 2 – Ammonia-Air Fuel Cell System Schematic

Figure 2 shows a flow schematic of the ammonia-air system. Ammonia, in standard commercial tankage, is stored as a liquid and withdrawn as a vapor. A pressure regulator reduces the pressure to the system operating pressure of approximately 10 psig. The ammonia is fed to the dissociator where it is thermally dissociated to a mixture of 75% H_2, 25% N_2 by volume. This mixture contains a small amount ($\approx$ 100 ppm) of undissociated ammonia. This trace ammonia is removed in a scrubber prior to the fuel gas entering the fuel cell.

Within the fuel cell hydrogen from the dissociated ammonia stream is combined with oxygen from ambient air to produce electricity and water. Heat, at a rate approximately equal to the electrical power produced, is a byproduct of the reaction.

The hydrogen is not completely consumed in the fuel cell; a portion passes from the fuel cell to a catalytic combustor to provide heat for the endothermic dissociator reaction. Temperature control of the ammonia dissociator is performed by controlling the flow of fuel to the fuel cell, therefore the flow of excess fuel to the burner, in response to the dissociator temperature.

AMMONIA DISSOCIATOR

A cross section view of the ammonia dissociator is show in Figure 3. The dissociator assembly contains the catalytic dissociation chamber, the startup burner, catalytic fuel cell effluent combustor, heat exchangers, and associated thermal insulation.

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AMMONIA DISSOCIATOR

A cross section view of the ammonia dissociator is shown in Figure 3. The dissociator assembly contains the catalytic dissociation chamber, the startup burner, catalytic fuel cell exhaust combustor, heat exchangers, and associated thermal insulation

Not shown are thermocouples for temperature monitoring, control, and flame-failure safety.

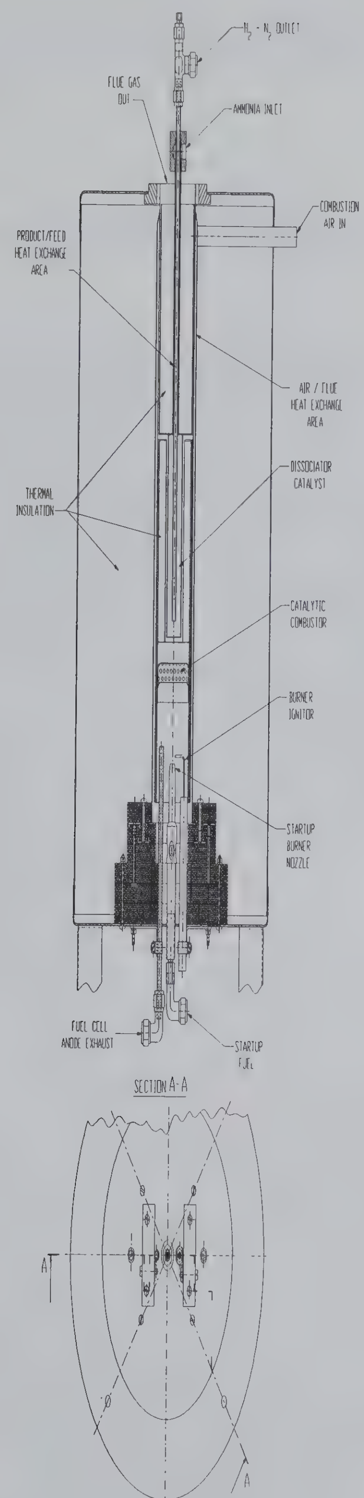

Figure 3 – Ammonia Dissociator

FUEL CELL SYSTEM

The fuel cell system installed in the HAR is shown in Figure 4.

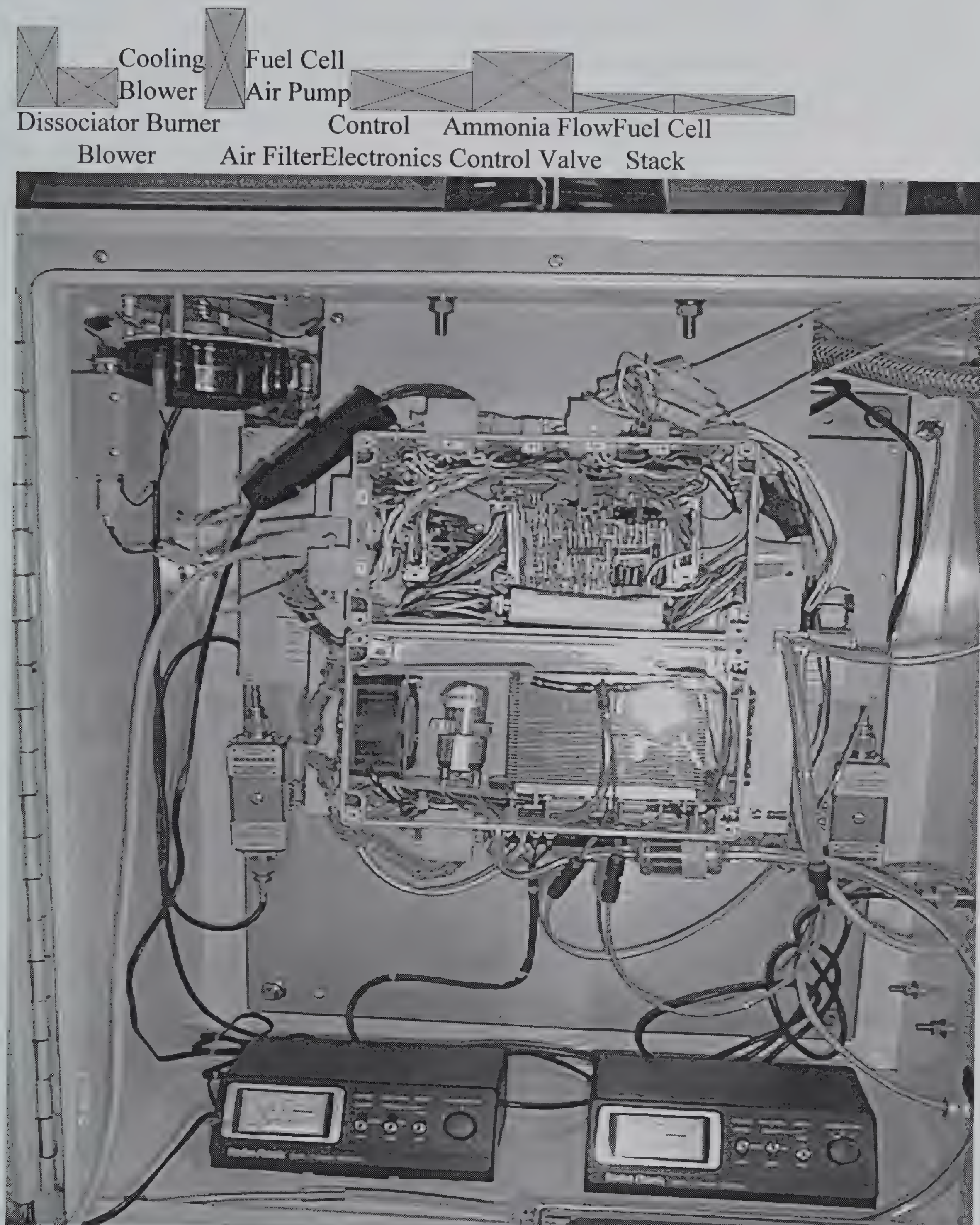

Figure 4 – Fuel Cell System

The fuel cell and auxiliaries are enclosed in a well-ventilated, weather-resistant enclosure. This enclosure also contains some dissociator auxiliaries and the control electronics for both the fuel cell subsystem and the dissociator subsystem. Ventilation is required to provide clean reaction air for the fuel cell and combustion air for the dissociator burner. Cooling air for the fuel cell stack is also drawn from within this enclosure. The large rate of air flow through this enclosure contributed to the freezing problems encountered during operation at low ambient temperatures.

In future systems insulation or heating, with waste heat, of this enclosure should be considered. Heat tracing of some lines, particularly exhaust lines, should be incorporated to avoid freezing.

TYPICAL SYSTEM PERFORMANCE

Figure 5 shows the performance of the HAR fuel cell system during a three-day period during January 1999. The fuel cell was powering the radio transmitter directly; no load-share battery was employed.

It can be seen that performance was stable over the majority of the period shown. Dissociator temperatures and ammonia flow rate remained steady. Stack power was nominally 25 watts. Two power peaks are shown. These peaks were caused by the cell phone answering calls and transmitting data. No explanation is known for the drop of power shown during the first phone activity.

Toward the end of this test, fluctuations may be seen in the dissociated ammonia flow rate. This is reflected in the variation observed in both dissociator temperatures. No distinct, corresponding variation is observed in the stack power. This is as expected because the hydrogen flow past the fuel cell anodes is greatly in excess of that required for electrochemical operation – the excess is burned to provide heat to the dissociator. The fluctuations are attributed to the onset of ice accumulation within process lines, primarily the fuel cell anode exhaust.

At approximately the 10:00 a.m. point the system shut down. Upon examination, both the anode exhaust tube and the cathode exhaust were found to be blocked by ice.

COST BENEFIT ANALYSIS

The potential benefit of employing the ammonia-fueled fuel cell system to power the HAR must be determined in relation to the existing HAR power system. Installation of the fuel cell system would allow displacement of the solar power system, and all but a small fraction of the associated battery power could be eliminated. (Batteries would be required only for system start-up.)

The displaced initial cost in the HAR from substituting a fuel cell system would amount to less than $1000. At the development stage of the ammonia-fueled fuel cell the cost is, of course, far greater than that of the standard HAR power system. Even for HAR production of approximately 50 units it is estimated that the fuel cell system cost would be in excess of $25,000. It is only in the case of ammonia-fueled fuel cells also being

developed for similar applications in far greater volumes (i.e., in the thousands) that the cost would become competitive with existing hardware.

If the initial cost posture of the fuel cell system were competitive with that of the conventional system, it would become important to examine other factors to compare the two approaches. Specifically, operating cost and reliability issues must be put in perspective. Since the solar system does not have a fueling requirement, the fuel cell system would be at a disadvantage from this point of view. However, it is estimated that the ammonia consumption would be only about 150 lbs. per year in this application; this would entail a cost merely in the neighborhood of $50 per year, including filling charges, for a fleet of ammonia-based systems. The fuel cell system, at maturity, would have advantage with regard to maintenance cost since those costs associated with battery maintenance and replacement could be avoided. Reliability issues also tend to favor such a system. Since fuel cell units would be able to operate in the absence of sunlight, they would not be vulnerable to occlusion or fouling. They could also be placed in shaded or covered areas and could be configured more compactly, thus providing far more siting flexibility. Finally, the fuel cell units would be less prone toward vandalism or theft.

CONCLUSIONS

This report describes a novel power system for a highway advisory radio. Development efforts led to attractive system integration and performance. Further effort is required to allow sustained operation at sub-zero temperatures.

The approach of using an ammonia-fueled fuel cell system is potentially attractive for this application from the points of view of maintenance, reliability, and siting issues. The initial cost of this system for the HAR application would be far too high to be competitive. Overcoming this cost disadvantage would require a similar system to be committed to high-volume commercialization.

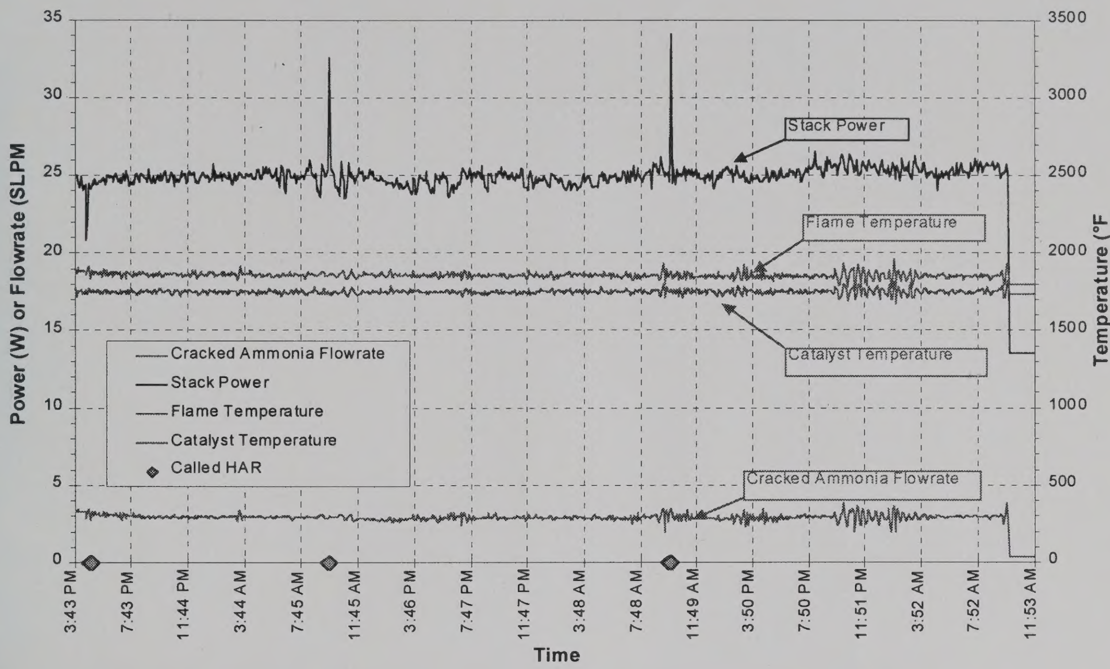

Figure 5: Performance of Ammonia Dissociator / Fuel Cell System During Field Test at Bedmins ter, NJ on 1/27/99-1/30/99.